Lithographic Apparatus and Device Manufacturing Method

Field

The present invention relates to a lithographic apparatus, a device manufacturing method and device manufactured thereby.

Background

A lithographic apparatus is a machine that applies a desired pattern onto a target portion of a substrate. Lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that circumstance, a patterning device, such as a mask, may be used to generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising part of, one or several dies) on a substrate (e.g. a silicon wafer) that has a layer of radiation-sensitive material (resist). In general, a single substrate will contain a network of adjacent target portions that are successively exposed. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through the projection beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction.

It has been proposed to immerse the substrate in the lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system and also increasing the depth of focus.)

However, submersing the substrate or substrate and substrate table in a bath of liquid (see for example United States patent US 4,509,852, hereby incorporated in its entirety by reference) means that there is a large body of liquid that must be accelerated during a scanning exposure. This requires additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

One of the solutions proposed is for a liquid supply system to provide liquid on only a

localized area of the substrate and in between the final element of the projection system and the substrate using a liquid supply system (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in PCT patent application WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a –X direction, liquid is supplied at the +X side of the element and taken up at the –X side. Figure 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of in- and out-lets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element.

Summary

In addition to the solution described above, a liquid supply system in a second solution may be provided that comprises a seal member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. The seal member is substantially stationary relative to the projection system in the XY plane though there may be some relative movement in the Z direction (in the direction of the optical axis). A seal is formed between the seal member and the surface of the substrate. In an embodiment, the seal is a contactless seal such as a gas seal. Such a system is disclosed in U.S. patent applications US 10/705,805 and US 10/705,783, both hereby incorporated in their entirety by reference.

A third solution that may be provided comprises a member attached to the projection system which forms a hollow space underneath the final element of the projection system. The bottom of the member is provided close enough to the surface of the substrate such that capillary forces are strong enough to contain the immersion liquid in the hollow space

created by the member between the final element of the projection system and the substrate.

While all of the above localized area solutions overcome the problem of needing to accelerate a large body of liquid, each of the solutions may be improved. For example, the first solution has proved to be hard to implement without large and uncontrolled liquid spillage. A further example is that the second and third solutions may deleteriously transmit disturbance forces to the substrate and/or projection system because of their close interaction with the surface of the substrate which is necessary in order to keep the liquid in the space. Furthermore, each of the solutions may not be particularly well suited for imaging objects of different height on the substrate table, such as through lens sensors. There is not a great deal of available space with these systems between the projection system and the substrate and building a liquid supply system which can operate at high NA can be difficult. Each of the solutions may present difficulties with the imaging of edge portions of the substrate, such as the gas seal may become unbalanced when it is partly positioned over the edge of the substrate and/or the capillary force can be lost when imaging edge portions. These solutions all work best with a low free working distance (which would advantageously be higher) and with high fluid pressures (which would advantageously be lower).

Accordingly, it would be advantageous, for example, to provide immersion liquid to a space between a projection system and the substrate without some or all of the above problems, in particular avoiding significant transmission of disturbance forces to the substrate.

According to an aspect, there is provided a lithographic apparatus comprising:

an illumination system configured to provide a beam of radiation;

a support structure configured to hold a patterning device, the patterning device configured to impart the beam with a pattern in its cross-section;

a substrate table configured to hold a substrate;

a projection system configured to project the patterned beam onto a target portion of the substrate; and

a liquid supply system configured to provide an immersion liquid to a space between the substrate and the projection system, the liquid supply system comprising a barrier member extending along at least a part of the boundary of the space and being in a position

relative to an object on the substrate table so that any capillary pressure generated by the immersion liquid between the barrier member and the object is not large enough to constrain the immersion liquid in the space,

wherein no seal is provided between the barrier member and the object.

In this way, in use, the immersion liquid is allowed to leak out of the space between the bottom of the barrier member and the substrate and is thereby not constrained in the space. Thus, the transmission of disturbance forces between the projection system, the barrier member and the substrate may be reduced or minimized. Furthermore, a high rate of liquid replenishment in the space may be possible without the necessity for the use of high liquid pressures. The force in the direction of the optical axis on the substrate table may also be reduced and be more constant in comparison to other liquid supply systems. Also, unlike with other supply systems, the imaging of edge portions may become easier as complicated measures are not necessary as the barrier member passes over the edge of the substrate as there is no seal to be disturbed at the edge of the substrate. The simplicity of the barrier member may be increased as only liquid inlets are required and no gas supplies. The lack of gas supplies means that the chance of bubble formation in the immersion liquid which can deleteriously affect the imaging quality may reduced or minimized. Finally, a larger free working distance (the distance between the projection system and the substrate) may be increased compared to other supply systems.

In an embodiment, the apparatus further comprises at least one outlet to remove immersion liquid, the outlet being radially outwardly of the barrier member. In this way immersion liquid which has spilled from the localized area of the supply system (i.e. the area under the projection system) may be collected without adding to the complexity of the barrier member and without substantially transferring disturbance forces to the substrate and/or substrate table. In one embodiment the outlet is on the substrate table.

In an embodiment, the barrier member is mechanically isolated from the projection system so that disturbance forces are not automatically transmitted to the projection system by the barrier member. In an embodiment, the barrier member is connected to a base frame which supports the substrate table and/or a projection system frame which supports the projection system. In an embodiment, the barrier member is free to move in the direction of an optical axis of the projection system.

For flexibility of the system, the apparatus may comprise an actuator configured to adjust the height and/or tilt of the barrier member relative to the substrate.

According to a further aspect, there is provided a device manufacturing method comprising:

providing an immersion liquid to a space between a substrate on a substrate table and a projection system, a barrier member extending along at least a part of the boundary of the space;

allowing immersion liquid to leak between the barrier member and an object on the substrate table by positioning at least one of the barrier member and the object so that any capillary pressure generated by the immersion liquid between the barrier member and the object is not large enough to constrain the immersion liquid in the space; and

projecting a patterned beam of radiation onto a target portion of the substrate using the projection system.

According to a further aspect, there is provided a device manufactured according to the above-referenced device manufacturing method and/or by the above-referenced lithographic apparatus.

Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal displays (LCDs), thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "wafer" or "die" herein may be considered as synonymous with the more general terms "substrate" or "target portion", respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist) or a metrology or inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

The terms "radiation" and "beam" used herein encompass all types of electromagnetic

radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of 365, 248, 193, 157 or 126 nm).

The term "patterning device" used herein should be broadly interpreted as referring to any device that can be used to impart a projection beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the projection beam may not exactly correspond to the desired pattern in the target portion of the substrate. Generally, the pattern imparted to the projection beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

A patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions; in this manner, the reflected beam is patterned. In each example of a patterning device, the support structure may be a frame or table, for example, which may be fixed or movable as required and which may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms "reticle" or "mask" herein may be considered synonymous with the more general term "patterning device".

The term "projection system" used herein should be broadly interpreted as encompassing various types of projection system, including refractive optical systems, reflective optical systems, and catadioptric optical systems, as appropriate for example for the exposure radiation being used, or for other factors such as the use of an immersion fluid or the use of a vacuum. Any use of the term "lens" herein may be considered as synonymous with the more general term "projection system".

The illumination system may also encompass various types of optical components, including refractive, reflective, and catadioptric optical components for directing, shaping, or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens".

The lithographic apparatus may be of a type having two (dual stage) or more substrate

tables (and/or two or more mask tables). In such "multiple stage" machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;

Figure 2 illustrates, in cross-section, a liquid supply system of the prior art;

Figure 3 illustrates, in plan, the liquid supply system of Figure 2; and

Figure 4 illustrates the liquid supply system according to an embodiment of the present invention.

Detailed Description

Figure 1 schematically depicts a lithographic apparatus according to a particular embodiment of the invention. The apparatus comprises:

- an illumination system (illuminator) IL for providing a projection beam PB of radiation (e.g. UV radiation).
- a first support structure (e.g. a mask table) MT for supporting a patterning device (e.g. a mask) MA and connected to a first positioning device PM for accurately positioning the patterning device with respect to item PL;
- a substrate table (e.g. a wafer table) WT for holding a substrate (e.g. a resist-coated wafer) W and connected to a second positioning device PW for accurately positioning the substrate with respect to item PL; and
- a projection system (e.g. a refractive projection lens) PL for imaging a pattern imparted to the projection beam PB by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g. employing a programmable mirror array of a type as referred to above).

The illuminator IL receives a beam of radiation from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD comprising for example suitable directing mirrors and/or a beam expander. In other cases the source may be integral part of the apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

The illuminator IL may comprise an adjusting device AM for adjusting the angular intensity distribution of the beam. Generally, at least the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL generally comprises various other components, such as an integrator IN and a condenser CO. The illuminator provides a conditioned beam of radiation, referred to as the projection beam PB, having a desired uniformity and intensity distribution in its cross-section.

The projection beam PB is incident on the mask MA, which is held on the mask table MT. Having traversed the mask MA, the projection beam PB passes through the lens PL, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioning device PW and position sensor IF (e.g. an interferometric device), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning device PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the object tables MT and WT will be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the positioning devices PM and PW. However, in the case of a stepper (as opposed to a scanner) the mask table MT may be

connected to a short stroke actuator only, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

The depicted apparatus can be used in the following preferred modes:

1. In step mode, the mask table MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the projection beam is projected onto a target portion C in one go (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

2. In scan mode, the mask table MT and the substrate table WT are scanned synchronously while a pattern imparted to the projection beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the mask table MT is determined by the (de-)magnification and image reversal characteristics of the projection system PL. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

3. In another mode, the mask table MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the projection beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes a programmable patterning device, such as a programmable mirror array of a type as referred to above.

Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

Figure 4 shows a liquid supply system according to an embodiment of the present invention. The liquid supply system comprises a barrier member 10. The barrier member 10 surrounds the final element of the projection system PL. The barrier member 10 extends along at least part of the boundary of a space between the final element of the projection

system PL and the substrate W. The space generally bounded by the projection system PL, the barrier member 10 and the substrate W is filled with an immersion liquid 5.

There is no seal between the barrier member 10 and the substrate W. The barrier member 10 is far enough above the substrate W such that capillary forces do not act to contain the immersion liquid 5 in the space between the final element of the projection system PL and the substrate W bounded by the barrier member 10; in use, such as during scanning or stepping, immersion liquid 5 flows out under the barrier member 10 as illustrated because any capillary pressure generated in the gap between the bottom of the barrier member 10 and the top of the substrate W is not large enough to contain the liquid. The barrier member 10 may be connected to the base frame BF, the projection system frame RF and/or another frame. In an embodiment, the barrier member 10 is mechanically isolated from the projection system PL so that disturbances forces imparted on or generated by the barrier member 10 can be prevented or at least limited from being transmitted to the projection system PL.

No provision is made, for example, during scanning, to seal the space 5 to avoid loss of immersion liquid. The level of immersion liquid in the passage between the projection system PL and the barrier member 10 is maintained as constant as possible by the provision of immersion liquid through one or more inlet ports 20.

The barrier member 10 may be comprised solely of the one or more inlet ports 20 so that the arrangement is similar to that shown in Figure 3 except the outlet ports OUT are inlet ports. Thus, the one or more inlet ports 20 are positioned circumferentially around the optical axis of the apparatus.

Immersion liquid 5 is provided to the space through the one or more inlet ports 20 which is/are formed on a bottom inner edge of the generally annular shaped barrier member 10. The barrier member 10 may be other shapes whether closed (e.g., rectangular) or open (e.g., U-shaped). A chamber 24 provided between the one or more inlet ports 20 and the supply of immersion liquid 22, ensures that immersion liquid is provided into the space at an even pressure around the inner periphery of the barrier member 10 even though the sources of immersion liquid may be provided via one or more discrete channels 22 (as opposed to, for example, a continuous groove). The one or more inlet ports 20 may be a continuous groove.

As is illustrated in Figure 4, the barrier member 10 extends below the one or more inlet ports 20 radially outwardly of the one or more inlet ports 20, whereas radially inwardly the barrier member 10 is further displaced from the substrate W than on the other side of the one or more inlet ports 20. This design reduces the chance of gas inclusion at the one or more inlet ports 20.

In order to avoid significant capillary forces being generated by immersion liquid 5 filling the gap between the bottom of the barrier member 10 and the top of the substrate W, the bottom of the barrier member is, in an embodiment, at least 50 μm from the substrate W. In an embodiment, the distance is substantially 100 μm or substantially 150 μm. A distance of over 300 μm (even 400 μm) may not be uncommon, for instance during scanning of sensors 70. These are typical distances if the immersion liquid is water. The required distance may be different for other liquids. The barrier member 10 may be moveable in the Z axis 40 such that the distance between the substrate W (or any other object) and the barrier member 10 can be adjusted. The barrier member may also be moveable about one or more axes substantially perpendicular to the Z axis 40 such that the tilt between the substrate W (or any other object) and the barrier member 10 can be adjusted. Alternatively or in addition, the substrate table WT may be moveable in the Z axis 40 to adjust the distance between the substrate W (or any other object) and the barrier member 10 and/or moveable about one or more axes substantially perpendicular to the Z axis 40 to adjust a tilt between the substrate W (or any other object) and the barrier member 10.

Therefore, in use, the immersion liquid is spilt radially outwardly of the barrier member 10 and flows on the substrate (or object (e.g. substrate table WT)) and immersion liquid can be provided through the one or more inlet ports 20 at a low pressure. If the immersion liquid is water, a pressure of about 1000 Pa in the one or more inlet ports 20 is about right and with a suitable restriction between the supply channel and the containment under the projection system, a pressure of about 100 Pa can be achieved under the projection system. Thus, a small constant Z force on the substrate table WT is provided of about 50 mN.

In order to remove the immersion liquid which has been spilled from the liquid supply system, one or more of the outlets 60, 63, 66 may be provided. The outlets are

positioned radially outwardly of the barrier member 10 and do not form part of the barrier member 10. Any arrangement can be used for outlets and three possibilities are shown in Figure 4. A typical outlet 60 might be one which is connected either to the base frame BF or the projection system frame RF (shown in Figure 1) and which removes liquid from the surface of the substrate W or substrate table WT or a substrate table mounted sensor 70 or a shutter member 80 (described in more detail hereafter). Alternatively or in addition, one or more outlets 63 may be provided in the top surface of the substrate table WT and/or one or more outlets 66 can be provided at the edge of the substrate W. In order to avoid spillage, a rim 50 may be provided around the substrate table WT.

The liquid supply system may be used for imaging of through lens sensors 70 mounted on the substrate table WT as well as with a shutter member 80, which can be attached to the bottom of the barrier member 10 through a vacuum source, by magnets , etc. which ensures that the final element of the projection system PL is maintained wet during substrate W swap. Shutter members are described in more detail in U.S. patent application US 10/705,785, herein incorporated in its entirety by reference. For both the sensors 70 (which may be, for example, transmission image sensors (TIS)) and the shutter member 80, the barrier member 10 may be lowered towards the substrate W (and/or the substrate table WT may be raised towards the barrier member 10). No scanning takes place when the sensors 70 are imaged and during this time (and other times when no scanning takes place) the pressure of liquid in the barrier member 10 can be reduced such that a meniscus can be formed between the barrier member 10 and the substrate table WT so that less liquid escapes as well as perhaps lowering the barrier member 10.

Adaptive height control of the barrier member 10 could be used (see European patent application EP 03256643.2, herein incorporated in its entirety by reference) possibly based on the position of the substrate table WT with respect to the projection system.

While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.